Original Research

Correlation between Length of Life and Exposure to Air Pollution

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Abstract

According to the World Health Organization, air pollution contributes to shortened life expectancies of UE citizens by an average of 8.6 months. The aim of our study was to see if there is a relationship between exposure of inhabitants of cities to air pollution and the length of their lives, excluding deaths caused by external causes. Average annual concentrations of air pollutants such as PM_{10}, benzo(a)pyrene, cadmium and lead in PM_{10} were based on data from the measuring stations, while the concentrations of dioxins, furans and polychlorinated biphenyls were their own measurements. The average women's and men's life expectancies in 11 cities in the year 2015, after excluding accidents and suicides, were calculated on the basis of the registry of deaths. Inequalities in men's and women's life expectancies are significant between cities and there is a relationship between exposure to air pollutants and the length of men's and women's lives in each city, demonstrating a very strong correlation in the male population. An effective tool for identifying significant risk factors affecting human health seems to be the multiple regression model.

Keywords: life length, health inequalities, long-term exposure, air pollution, multiple regression

Introduction

The health status of the population is determined by health indicators, among which one of the most important is the average life expectancy. Life expectancy indicates general health efficiency in a society at a given time and reflects the reduction of mortality rates in all age groups, including such factors as: increasing living standards and education levels, a healthier lifestyle and better access to quality health services [1].

This indicator has its source in the mortality statistics and it expresses the average number of years, which person coming from a specific population at the age of x completed years, in a defined mortality condition is expected to live [2, 3]. To calculate the average life expectancy, there is a need to use mortality data, which can be classified into one of five basic causes of death: cardiovascular diseases, cancer, external causes of injuries and poisoning, respiratory diseases and diseases of the digestive system [4].

According to the International Statistical Classification of Diseases and Related Health Problems ICD-10, the group of external causes of diseases and deaths includes: accidents (including traffic accidents

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and other external causes of accident injuries), intentional self-injuries, assaults, complications of medical and surgical procedures, and consequences of external causes of illness and death [5]. In accordance with the official statistics, deaths caused by external causes are the third cause of death in Poland (after cardiovascular and cancer diseases), which can significantly affect the picture of the air pollution impact on life length [6]. It seems reasonable to use such measures of life expectancy, which includes only deaths from natural causes – as the real life length.

The average life expectancy between the EU Member States in the years 1980-2016 was very diverse, with a systematically growing tendency. In this period they increased by over 5 years. According to the Eurostat data, life expectancy at birth in the EU in 2016 amounted to 81.0 years (83.6 years for women and 78.2 years for men). In the years 2000-2016, the increase in life expectancy for men in EU Member States ranged from 2.8 years (in Lithuania) to 7.7 years (in Estonia), and among women from 2.1 years (in Sweden) to 5.8 years (in Estonia). In 2016, the differences between the highest and the lowest life expectancies among EU countries were 11.5 years for men and 7.8 for women. In the male population, the lowest value of the indicator was recorded in Lithuania (69.5 years), and the highest in Italy (81.0 years). The lowest life expectancy in the population of women was shown in Bulgaria (78.5 years), and the highest in Spain (86.3 years). In Poland, life expectancy is clearly shorter than the average in the EU countries; men live about 4.3 years less, and women about 1.6. In 2016, male residents lived an average 73.9 years and females about 8.0 years longer (82 years) [7]. The current life expectancy of Poles is equal to that, which occurred 17 years ago in 15 countries of the European Union [8].

The problem of health inequalities is a major challenge for public health in Europe and around the world, and the World Health Organization (WHO) emphasizes the importance of the environment as a very crucial determinant of health. According to WHO and the International Agency for Research on Cancer (IARC), air pollution contributes to shortening the average life expectancy of the EU Member States by an average of 8.6 months – up from about 3 months in Finland and Ireland to more than 13 months in Belgium. Additionally, the correlation between exposure to air pollution and increased incidence of cancer diseases, in particular lung cancer, as well as respiratory and cardiovascular diseases in the European population, has been proven [1, 9, 10].

The aim of our study was to investigate the relationship between long-term exposure to the mixture of air pollutants such as: particulate matter PM_{10}, benzo(a)pyrene, cadmium and lead as well as dioxins, furans and polychlorinated biphenyls, and the life length of inhabitants of selected cities of Silesia Province.

A study of the correlation between life length and long-term exposure to air pollution should include populations with comparable population sizes living in areas with different levels of air pollution.

Material and Methods

The research material were data on concentrations of selected air pollutants and epidemiological data concerning the real-life expectancies of women and men from selected cities with county rights in Silesia Province, Poland.

The research was carried out on the basis of life length data of inhabitants from 11 selected cities with county rights in Silesia Province (Bytom, Chorzów, Dąbrowa Górnicza, Gliwice, Jaworzno, Katowice, Ruda Śląska, Rybnik, Sosnowiec, Tychy and Zabrze). These are the cities where population is around 100 000+ inhabitants. The average population of women and men across 11 cities in this period of time was 1 752 477 people (840 418 men and 912 059 women) [11].

Data on average annual PM_{10} concentration of suspended particulate matter and benzo(a)pyrene, cadmium and lead adsorbed on it, for the years 1989-2008, were obtained from the Provincial Sanitary-Epidemiological Station in Katowice and the Provincial Environmental Protection Inspectorate in Katowice.

State Environmental Monitoring does not carry out measurements of air pollution with dioxins, furans and polychlorinated biphenyls (PCBs). Consequently, our own measurements of the concentrations of these compounds in the air were conducted during the period between December 2014 and February 2015 using the passive air sampling method. The samples were analysed by the certified testing laboratory of E&H Services, A.S. (Czech Republic). Certificate of accreditation No. 4/2016 was issued on the basis of the assessment of fulfilment of the accreditation criteria in accordance with CSN EN ISO/IEC 17025:2005.

Concentration levels of air pollutants in the analysed cities, for example PM_{10}, were very diverse. In extreme cases, the lowest average concentration of PM_{10}, for the years 1989-2002, was recorded in Dąbrowa Górnicza (80.79 µg/m³), while the highest was in Chorzów (112.57 µg/m³). In the next 6 years (2003-2008), the average concentration values of suspended particulate matter in the air were almost twice lower, obtaining the lowest value in Jaworzno (44.0 µg/m³), and the highest in Zabrze (71.67 µg/m³).

The Central Statistical Office of Poland made available data on the number of deaths, including gender and age of the deceased, and the causes of deaths (according to the International Statistical Classification of Diseases and Related Health Problems ICD-10) in selected cities with county rights in Silesia Province in the years 2002-2015. These data were used to calculate the real life length and life length excluding deaths caused by external causes.

The real life length was calculated using the following equation:

$$= \frac{\text{the number of years lived by people who died in a specific year}}{\text{number of people who died in a specific year}}$$

The life length (excluding deaths caused by external causes) was calculated using the following equation:

$$= \frac{\begin{array}{c}\text{the number of years lived by people who died in a specific year} \\ \text{(excluding deaths caused by external causes)}\end{array}}{\text{number of people who died in a specific year}}$$

In the regression analysis we focused on data from 11 cities. The relative cumulative exposure values for PM_{10}, BaP and cadmium, over the period 1989-2008, were calculated by taking the lowest value found among all cities over the study period (set to 1) and converting all other values to multiples of this value. To get a cumulative value for each city in all years, the values for each year were summed. Because the dioxins (PCDDs), furans (PCDFs), dioxin-like polychlorinated biphenyls (dl-PCBs) and non-dioxin-like polychlorinated biphenyls (ndl-PCBs) were measured at one point in time (in 2014 or 2015), the cumulative exposure score was not calculated. Relative exposure values were calculated by taking the lowest measurement for each pollutant (set to 1) and converting all other values to multiples of this value.

Collected epidemiological data (life length, excluding deaths caused by external causes) and air pollution data were evaluated for normal distribution by the Shapiro-Wilk test with a confidence level of 95%. A multiple regression analysis was carried out to assess the combined effect of pollutants on men's and woman's life expectancies. All analyses were carried out using a threshold for statistical significance set at a value of p≤0.05. Statistical analysis of the collected material was carried out using Microsoft Office (MS Word, MS Excel, MS Access) and Statistica 12 StatSoft Poland, with the addition of the medical kit.

Results and Discussion

The average life expectancy is one of the basic measures of population health status. The methodology used to calculate this indicator is recommended by the World Health Organization, which provides the possibility to compare the average life expectancy between countries in the world. This methodology is also used in Poland. In order to investigate the relationship between long-term exposure to air pollution with PM_{10} suspended dust and the mixture of compounds adsorbed on it as well as dioxins, furans and polychlorinated biphenyls, the life expectancy of Silesian inhabitants was used. The results in Table 1 show the differences between the commonly used life expectancy values and the real life length excluding the deaths from external causes.

Average life expectancy, life length and life length excluding the deaths from external causes are measures related to life expectancy, but the values of these indicators are clearly different. Table 1 presents their comparison in the population of women and men in selected cities of Silesia Province in 2002. The biggest difference between average life expectancy and life length, both in the population of women and men, was demonstrated in Zabrze: 12.8 and 10 years, respectively.

The percentage of external causes of deaths in total mortality in the analysed population from selected cities was significantly higher in the male population (7.7-11.4%) compared to women (3-6.5%). The highest value, both among men and women, was recorded in Dąbrowa Górnicza. Among the inhabitants of Gliwice and the male population of Jaworzno, external causes constituted the smallest percentage of total mortality (Table 1).

On the basis of the data contained in Table 2, the life length of the population from selected cities in 2015 was compared. In case of both analyzed measurement, among the population of women and men, the longest life length was demonstrated in Gliwice, and the shortest in Ruda Śląska. Table 2 also indicates the percentage share of external causes of death in total mortality. In the female population, external causes accounted for 1.9-4.1%, and in the male population 5-7% of total deaths in the analysed cities.

The health efficiency of the society of 11 cities with county rights in Silesia Province, living in conditions of long-lasting diversification between cities' air pollution, was referenced to the life length. The research shows that not the commonly used average life expectancy but actual life length should be taken into account when looking for the relationship between exposure to air pollution and life length. The average real life length in the population of women and men was obtained on the basis of mortality from natural causes, after excluding deaths classified by ICD-10 to deaths caused by external causes (V01-Y98) [5].

According to the data presented in Tables 1 and 2, deaths due to external causes understate the average life length for men and women, causing it to be lower than life expectancy calculated for the same population. Furthermore, the higher death rate due to external causes affects men, which increases the existing difference between the average life expectancy depending on gender. Considering that the share of external causes of death in total mortality may constitute an interference factor in the study investigating the impact of air pollution on the life length of population, for statistical analyses, life length (excluding deaths caused by external causes) was taken into account.

Comparison of life expectancy in the EU countries indicates a large discrepancy between member states as well as between individual regions in these countries [7, 12]. One of the inequality causes in life expectancy may be environmental pollution – especially air pollution. Recent studies confirm the relationship

Table 1. Comparison of average life length indicators of the inhabitants of selected cities with county rights in Silesia Province in 2002.

City	Indicators determining life length - women (2002)				Indicators determining life length - men (2002)			
	Life expectancy*	Life length	Life length (excluding deaths caused by external causes)	% share of external causes in total mortality	Life expectancy*	Life length	Life length (excluding deaths caused by external causes)	% share of external causes in total mortality
Bytom	78.3	66.8	72.1	5.0	72.2	62.7	64.3	10.9
Chorzów	76.9	67.7	73.5	4.8	69.8	62.9	64.5	8.7
Dąbrowa Górnicza	78.8	69.0	74.7	6.5	69.6	64.4	66.8	11.4
Gliwice	78.5	68.2	74.1	3.0	70.1	63.4	64.8	8.4
Jaworzno	77.6	67.4	71.0	4.7	70.1	64.6	65.9	7.7
Katowice	77.5	68.8	73.8	3.8	70.9	64.5	65.9	8.4
Ruda Śląska	77.8	66.9	73.1	4.6	68.8	61.4	63.3	8.7
Rybnik	76.0	67.8	74.1	3.6	68.3	62.6	64.1	8.8
Sosnowiec	75.9	67.9	72.5	5.4	68.5	64.1	66.0	10.2
Tychy	75.0	66.9	71.1	5.2	65.2	64.1	66.0	10.2
Zabrze	78.6	65.8	71.1	3.8	71.7	61.7	63.6	9.5

* Source: Based on data from Central Statistical Office of Poland

Legend:

the highest value of difference between life expectancy and life length

the highest value of percentage share of external causes in total mortality

the lowest value of percentage share of external causes in total mortality

Table 2. Comparison of average life length indicators of inhabitants of selected cities with county rights in Silesia Province in 2015.

City	Indicators in women population (2015)			Indicators in men population (2015)		
	Life length	Life length (excluding deaths caused by external causes)	% share of external causes in total mortality	Life length	Life length (excluding deaths caused by external causes)	% share of external causes in total mortality
Bytom	74.3	74.3	2.5	67.2	68.3	6.4
Chorzów	76.1	76.4	3.8	67.9	68.9	6.2
Dąbrowa Górnicza	75.4	75.7	2.9	68.0	68.9	6.1
Gliwice	76.9	77.0	3.2	69.0	70.1	6.3
Jaworzno	75.4	75.8	3.8	68.8	69.5	5.0
Katowice	76.1	76.4	3.8	68.4	69.5	7.0
Ruda Śląska	74.1	74.1	4.1	65.9	66.9	6.8
Rybnik	76.1	76.5	3.0	67.4	68.4	6.5
Sosnowiec	76.0	76.2	3.3	67.4	68.3	5.8
Tychy	75.5	75.7	1.9	69.0	69.9	6.3
Zabrze	74.7	75.0	3.5	66.4	67.5	6.1

Legend:

▨ the lowest value of life length (excluding deaths caused by external causes)

▨ the highest value of life length (excluding deaths caused by external causes)

▨ the highest value of percentage share of external causes in total mortality

▨ the lowest value of percentage share of external causes in total mortality

between the exposure of residents to air pollution, the length of exposure and the occurrence of chronic diseases, and therefore the impact on length of life [13-17]. According to WHO data, in 2016 91% of the world's population lived and worked in places where the WHO air quality guidelines were not met. It is estimated that in 2016 outdoor air pollution in cities and in rural areas caused 4.2 million premature deaths worldwide. About 91% of these premature deaths occurred in low- and middle-income countries, and the largest in Southeast Asia and the region of the Western Pacific [18]. By lowering the level of air pollution, countries can reduce the burden of chronic diseases such

as lung cancer, stroke, heart diseases, and respiratory diseases.

The conducted research shows that similarly to Silesia Province, the reduction of air pollution could significantly reduce the number of chronic diseases. Silesia is characterized by the emission of significant amounts of air pollutants into the atmosphere from both numerous industrial sources and households, heated with coal or other fuels, often of poor quality.

Data on concentrations of PM_{10}, cadmium and benzo(a)pyrene in suspended dust fraction PM_{10} were rearranged in relation to the minimum values recorded in 2008 (the year with the lowest values in the 20-year

Table 3. Modeling the correlation between the mixture of air pollutants and the life length of men (excluding deaths caused by external causes) in Silesia Province in 2015; multiple regression using ranking in relation to the lowest average value of air pollution.

R = 0.95056931 R^2 = 0.90358201 p<0.048			
Variables	**beta±statistical error beta**	**B±statistical error B**	**p**
PM_{10}	**-3.563±0.716**	**-0.512±0.102**	**0.007**
Cd w PM_{10}	0.755±0.327	0.017±0.007	0.082
B(a)P w PM_{10}	2.88±0.728	0.120±0.030	0.167
PCDD/F	0.811±0.213	2.086±0.549	0.191
dl-PCBs	**-0.421±0.257**	**-0.652±0.397**	**0.017**
ndl-PCBs	**-0.680±0.284**	**-0.568±0.238**	**0.007**

Table 4. Modeling the correlation between the mixture of air pollutants and the life length of women (excluding deaths caused by external causes) in Silesia Province in 2015; multiple regression using ranking in relation to the lowest average value of air pollution.

R = 0.85590621 R^2 = 0.73257544 $p<0.029$			
Variables	**beta±statistical error beta**	**B±statistical error B**	**p**
PM_{10}	**-3.364±1.193**	**-0.451±0.160**	**0.047**
Cd w PM_{10}	0.232±0.545	0.005±0.012	0.629
B(a)P w PM_{10}	3.426±1.213	0.133±0.047	0.476
PCDD/F	0.668±0.355	1.604±0.853	0.133
dl-PCBs	**-0.707±0.428**	**-1.021±0.618**	**0.017**
ndl-PCBs	-0.511±0.474	-0.399±0.370	0.341

exposure period) in the cities selected for research. The final value, used in the multiple regression model, was the sum of the annual multiplicities of the minimum concentration value for each pollutant tested in each city over a 20-year period (1989-2008). Data on the concentrations of dioxins, furans and polychlorinated biphenyls were compared to the smallest values recorded during the heating period at the turn of 2014 and 2015.

Considering the simultaneous occurrence of all analyzed factors whose average concentrations have been set in relation to the lowest average value, the results of multiple regression suggested that the combined effect of the inhalation exposure to the mixture consisting of dioxin-like polychlorinated biphenyls (dl-PCBs), non-dioxin-like polychlorinated biphenyls (ndl-PCBs) and particulate matter PM_{10} were expressed with reduced life length of men, and this relationship was statistically significant. The calculated correlation was almost perfect (R = 0.95) (Table 3).

The foregoing model showed that reducing the average annual PM_{10} concentration by 29 $\mu g/m^3$ of air (the lowest value of which is the basis for ranking cities in relation to particulate matter pollution) could extend life length of men by more than half a year (0.51 years). Additionaly, reducing air pollution with dioxin-like PCB compounds by 4.3 fg I-TEQ/m^3 of air (the lowest value which is the basis for ranking cities in relation to dl-PCBs), can extend men's life length by almost 8 months (0.66 years), and non-dioxin-like PCB compounds by 17.5 pg/m^3 of air (the lowest value of which is the basis for ranking cities in relation to ndl-PCBs) by almost 7 months (0.57 years).

Considering the simultaneous occurrence of all analysed factors whose average concentrations have been set in relation to the lowest average value, the multiple regression model showed a statistically significant impact of air pollution on life length (excluding deaths caused by external causes) among women in selected cities with county rights in Silesia Province (Table 4).

The analysis showed that reducing the average annual PM_{10} concentration by 29 $\mu g/m^3$ of air (the lowest value of which was the basis for ranking cities

in relation to particulate matter pollution) could extend women's life length by almost 6 months (0.45 years). Furthermore, reducing air pollution with dioxin-like PCB compounds by 4.3 fg I-TEQ/m^3 of air (the lowest value which was the basis for ranking cities in relation to dl-PCBs) could extend women's life length by about a year (1.02 years).

A similar relationship was shown by other researchers, indicating that reduction of PM_{10} suspended particulate matter by 1 $\mu g/m^3$ extends the life expectancy of men by 0.1 years [19]. The Aphekom project has shown that reducing airborne $PM_{2.5}$ to levels indicated by WHO could prevent 19 000 cases of premature deaths [20]. According to Nigerian and Indian researchers, the life expectancy of their respective countries' inhabitants could increase after the reduction of air pollution to the WHO value, depending on the initial concentration of particulate matter in the region, by about 1.6-2.9 years [21] and 2-9 months [22]. Research conducted by Pope et al. showed that in 1970-2000 in cities in the United States, the concentration of particulate matter was reduced by 10 $\mu g/m^3$ of air, which resulted in a longer life expectancy of 0.61±0.2 years [23, 24]. Data analysis concerning the PM_{10} concentrations in Silesian cities, conducted by Kowalski et al., has proved that a reduction of short-term exposure to PM_{10} by 5 $\mu g/m^3$ can minimize the number of deaths per year by 2.6-2.75 per 100 000 inhabitants [25].

Numerous scientific reports have confirmed that the increase in the concentration of 10 $\mu g/m^3$ dust in the air shortens the life expectancy of people by 0.64 to 1.37 years (1.11 years in the Netherlands, 1.37 in Finland, 0.80 in Canada, 0.64 in China, and 0.90 in Spain) [26-28]. The undesirable effects of high concentrations of particulate matter to population health are also confirmed by Li et al., showing that an increase in $PM_{2.5}$ and PM_{10} concentration by 10 $\mu g/m^3$ air will increase the percentage of premature deaths for all causes by 0.17% and 0.15% [29], which is consistent with other reports in this regard [30, 31].

Inequalities in the health condition of the population, resulting from too high concentrations of dust suspended in the air, can also be expressed using other indicators, e.g. the number of years of life lost (YLL) [32, 33]. According to data from the European Environment Agency (EEA), the value of this measure in Poland is one of the highest in Europe (1520). The lowest values of this indicator have been recorded in Iceland (269) and Sweden (307) [32].

Despite many studies on the toxicity of dioxins, polychlorinated biphenyls and their congeners, there is little information in the scientific literature on the relationship between air pollution by chlorinated persistent organic compounds and the life expectancy of society.

The analysis showed that reducing air pollution with dioxin-like PCB compounds by 4.3 fg I-TEQ/m^3 air, and non-dioxin-like PCBs compounds by 17.5 pg/m^3 air can extend men's life by about 8 and 7 months, respectively. In addition, reducing air pollution with dioxin-like PCB compounds by 4.3 fg I-TEQ/m^3 air can extend women's lives by up to one year.

Research carried out by Dziubanek et al. in 12 Silesian cities showed that the reduction of PCDD/Fs and dl-PCBs of 10 fg I-TEQ/m^3 could extend life expectancy of women by approximately 4 months (0.3 years) [34].

Conclusions

According to the studies, in search of the relationship between exposure to air pollution and life length, the actual life length (without deaths caused by external causes) should be taken into account, not commonly used average life expectancy.

The use of a multiple regression model in studies on the effects of long-term population exposure to dust pollutants has demonstrated the importance of PM_{10}, dl-PCBs and ndl-PCBs in inhalation effects on life lengths of women and men.

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Conflict of Interest

The authors declare no conflict of interest.

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